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An Intermediate-Mass Black Hole in the Dwarf Seyfert 1 Galaxy POX 52

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Abstract. We describe new observations of POX 52, a previously known but nearly forgotten example of a dwarf galaxy with an active nucleus. While POX 52 was originally thought to be a Seyfert 2 galaxy, the new data reveal an emission-line spectrum very similar to that of the dwarf Seyfert 1 galaxy NGC 4395, with clear broad components to the permitted line profiles. The host galaxy appears to be a dwarf elliptical; this is the only known case of a Seyfert nucleus in a galaxy of this type. Applying scaling relations to estimate the black hole mass from the broad H β linewidth and continuum luminosity, we find $M_{\text{BH}} \approx 1.6 \times 10^5 M_{\odot}$. The stellar velocity dispersion in the host galaxy is $36 \pm 5 \text{ km s}^{-1}$, also suggestive of a black hole mass of order $10^5 M_{\odot}$. Further searches for AGNs in dwarf galaxies can provide crucial constraints on the demographics of black holes in the mass range below $10^6 M_{\odot}$.

1. Introduction

Do dwarf galaxies host central black holes with masses below $10^6 M_{\odot}$? Beyond the Local Group, dynamical detections of black holes in this mass range are virtually impossible, but black holes might still reveal their presence by their accretion luminosity. Very few examples of active galactic nuclei (AGNs) in dwarf galaxies are known, however. The late-type, bulgeless spiral galaxy NGC 4395 has for several years been the only dwarf galaxy known to host a Seyfert 1 nucleus (Filippenko & Sargent 1989). A variety of observations suggest that its black hole has $M \approx 10^4 - 10^5 M_{\odot}$ (Filippenko & Ho 2003; Shih, Iwasawa, & Fabian 2003).

The galaxy POX 52 ($D = 93 \text{ Mpc}$ for $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$) was discovered by Kunth, Sargent, & Bothun (1987) in the POX objective-prism survey. They noted it as a unique example of a Seyfert 2 nucleus in a dwarf galaxy, which they concluded was a dwarf spiral. Despite the unusual properties of this object, no further follow-up observations of POX 52 were carried out since its initial discovery. Motivated by the possibility that POX 52 might contain a low-mass black hole similar to the one in NGC 4395, we obtained new optical spectra and images of POX 52 at the Keck and Las Campanas Observatories.

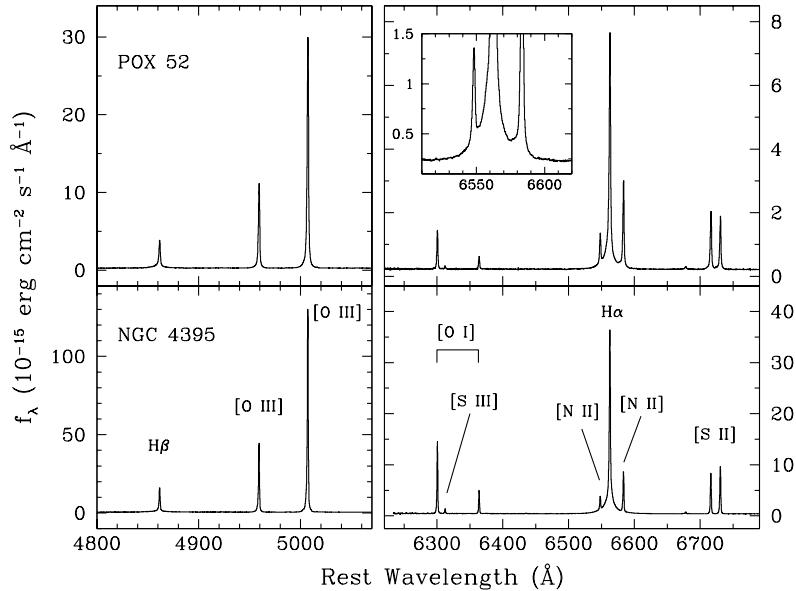


Figure 1. Keck ESI spectrum of POX 52 (upper panels) compared with NGC 4395 (lower panels). In the upper right panel, the inset shows a close-up view of the base of the $\text{H}\alpha$ emission line.

2. Observations and Results

The Keck ESI spectrum shown in Figure 1 demonstrates that POX 52 has an emission-line spectrum nearly identical to that of NGC 4395. In particular, POX 52 has similar broad wings on the $\text{H}\alpha$ emission line. Thus, POX 52 should actually be classified as a Type 1 AGN. This is a genuine Seyfert 1 galaxy; the broad component also appears on the higher-order Balmer emission lines as well as on $\text{He II } \lambda 4686$. In addition, high-excitation emission lines such as [Fe VII] are present. Based on the widths of the emission lines, POX 52 qualifies as a narrow-line Seyfert 1 (NLS1) galaxy, although it is an unusual member of that class since it does not have the strong Fe II emission or the small [O III]/ $\text{H}\beta$ ratio that are typical characteristics of NLS1s.

A virial estimate of the black hole mass can be derived from the broad $\text{H}\beta$ linewidth and AGN continuum luminosity, using scaling relations derived from reverberation mapping of Seyfert galaxies, and assuming gravitational motion of the broad-line clouds. We fit the $\text{H}\beta$ profile using a model consisting of a broad Gaussian plus a narrow component having the same shape as the [O III] $\lambda 5007$ line. The best-fitting model has a broad-line FWHM of 760 km s^{-1} . Combining this with the AGN continuum luminosity at 5100 Å using the scaling relations from Kaspi et al. (2000) gives a mass estimate of $\sim 1.6 \times 10^5 M_\odot$. This estimate is highly uncertain, since it requires extrapolating the scaling relations far beyond the mass range over which they have been calibrated. Nevertheless, this result suggests that POX 52 hosts a black hole with a mass that is substantially smaller than those of typical Seyfert galaxies. Also, if POX 52 has a spectral energy

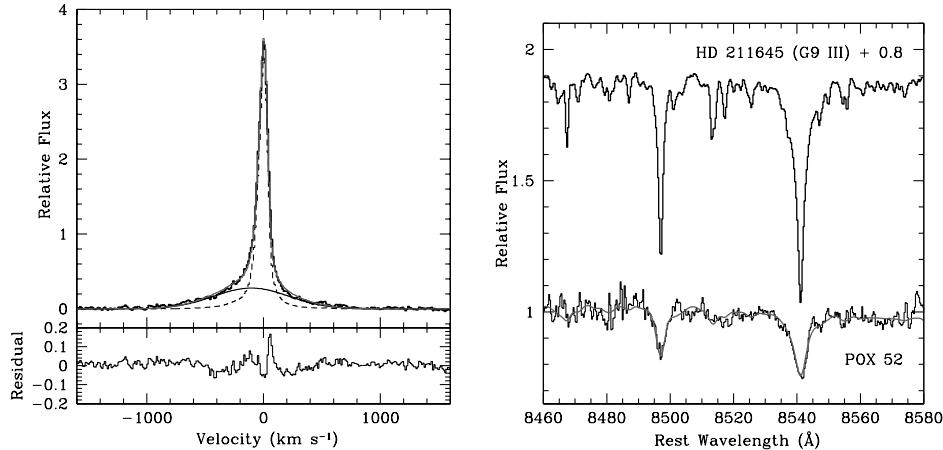


Figure 2. *Left panel:* Model fit to the H β emission line. The dashed curve is a scaled version of the [O III] line profile, used to model the narrow H β component. *Right panel:* The Ca II $\lambda\lambda 8498, 8542$ lines in POX 52. The model fit shows the G9 III template star diluted by a featureless continuum and broadened by $\sigma = 36 \text{ km s}^{-1}$.

distribution similar to that of NGC 4395 and if it is radiating at $L < L_{\text{Edd}}$, then a lower limit to its black hole mass is $3 \times 10^4 M_{\odot}$.

From the Ca II triplet lines in the ESI spectrum, we find a stellar velocity dispersion of $36 \pm 5 \text{ km s}^{-1}$. This is the second-smallest velocity dispersion known for any AGN; the smallest is NGC 4395 with $\sigma < 30 \text{ km s}^{-1}$ (Filippenko & Ho 2003). Extrapolating the $M_{\text{BH}} - \sigma$ relation of Tremaine et al. (2002) to $\sigma = 36 \text{ km s}^{-1}$, the expected black hole mass is $\sim 1.3 \times 10^5 M_{\odot}$. This is surprisingly close to the mass estimate derived from the H β linewidth. The [O III] emission line has $\text{FWHM} = 87 \pm 10 \text{ km s}^{-1}$ or $\sigma = 37 \pm 4 \text{ km s}^{-1}$, so the stellar and gaseous velocity dispersions are nearly equal.

New *BVRI* images of POX 52 were obtained at the 2.5-m du Pont telescope at Las Campanas Observatory in $0''.75$ seeing. Using the GALFIT profile-fitting code (Peng et al. 2002), we performed a decomposition into point-source and host galaxy components. An exponential profile gives an extremely poor fit to the host galaxy, while a Sérsic profile with an index of 3.6 ± 0.2 and an effective radius of $\sim 0.5 \text{ kpc}$ fits the galaxy adequately. The host galaxy has $M_B = -16.8 \text{ mag}$ and $B-V = 0.8 \text{ mag}$, consistent with the properties of a dwarf elliptical galaxy. No spiral structure or knots suggestive of star-forming regions are detected. In the fundamental plane, POX 52 lies close to the Virgo dwarf elliptical galaxies studied by Geha, Guhathakurta, & van der Marel (2003). Thus, it appears that POX 52 is the first known example of a Type 1 AGN in a dwarf elliptical galaxy.

3. Conclusions and Future Work

POX 52 is one of only two dwarf galaxies known to contain an AGN, and its black hole mass is likely to be of order $10^5 M_{\odot}$. We hope to obtain *HST* imaging

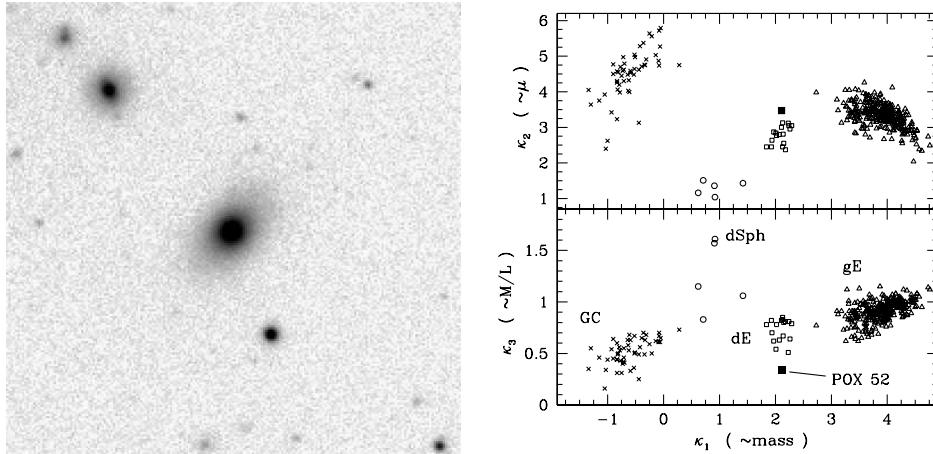


Figure 3. *Left panel:* R-band image centered on POX 52. The image size is 52'' on a side. *Right panel:* κ -space projections of the fundamental plane, including globular clusters (crosses), dwarf spheroidals (circles), giant ellipticals (triangles), dwarf ellipticals (open squares), and POX 52 (filled square). Literature data are from Burstein et al. (1997) and Geha et al. (2003).

in the future, for a definitive measurement of the host galaxy profile, as well as X-ray data from *Chandra* and/or *XMM-Newton* to study its AGN in greater detail and search for variability.

Currently, we have almost no information on the population of black holes with masses below $10^6 M_\odot$. Any constraints on black hole demographics in this mass range would be of particular interest for future gravitational wave experiments. Further searches for AGNs in dwarf galaxies may be the best way to improve this situation, and can yield at least a lower limit to the fraction of dwarf galaxies (both ellipticals and spirals) that contain central black holes. We are currently beginning a search of the SDSS data archive to identify additional dwarf galaxies with active nuclei.

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